



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Quality control of electro-acoustic transducers

Field of the invention

The invention relates to quality control of eg electro-acoustic transducers, and in particular to a method of quantitative measurement of non-linearities such as rub and buzz.

Background

10 The traditional method for measuring the energy of auditory signal deals with measuring the RMS (root-mean-square) value of the frequencies in the signal. This measure is based on the assumption that the signal only contains steady state frequency components. In the real world this will only be the case in very rare occasions. Normally signals exhibit dynamic behaviour with varying instantaneous energy. Pulses in auditory signals can in fact be expressed as abrupt changes in the instantaneous energy in the signals.

20 In audio products non-linearities can generate unwanted pulses that disturb the perceived quality, and can severely degrade the quality. The generated pulses will have different duration and energy, depending of the nature of the non-linearity. In some cases the duration of the pulses will be very short and the mean energy therefore will be very small even though the maximum instantaneous energy might have a relative high level. The traditional method by measuring the harmonic distortion will not be satisfactory in these cases. One of the classical examples is the distortion in class A and B amplifiers, where the crossover distortion in a class B amplifier disturb the ear at a much lower

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harmonic distortion ($< 1\%$) than the harmonic distortion caused by saturation in a class A amplifier (about 10 - 15%). Mechanically introduced noise in loudspeakers and microphones, known as "Rub and Buzz", will also occur as short pulses in the signal.

In relation to electro-acoustic transducers, such as microphones and loudspeakers and speaker transducers for use in telephones, the phenomenon referred to as "rub and buzz" is mechanically introduced noise caused by non-linearities in the transducers. These non-linearities are most often due to imperfections in the process of manufacturing the transducer, and it can be one or more of the following defects: loose litz wire, loose diaphragm, loose coil, misplaced diaphragm, scraping or dragging coil, air leak or other defects. These defects create short pulses due to abrupt changes in the instantaneous energy and are very disturbing to the human ear. The short impulses have relative low energy, and it can be difficult to detect the pulses when the signal is averaged using traditional RMS-FFT techniques. On the other hand, the maximum changes in the instantaneous energy are relatively high and can easily be detected with the measurement technique described here.

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Traditionally, Quality Control (QC) of audio products such as loudspeakers includes measurement of the frequency response, the impedance and rub and buzz. The measurement of the frequency response and the impedance are performed using well-known techniques such as FFT, MLS or TDS and apart from a careful design these measurements usually do not cause problems. Rub and buzz

is measured in different ways e.g. by tracking the harmonics using a swept sine or some kind of swept two-tone complex. These traditional rub and buzz measurement techniques usually have an inadequate performance and are
5 the Achilles heel of QC systems. This invention provides a method of measuring rub and buzz, which easily detects rub and buzz in loudspeakers and other audio products.

The method of the invention performs detection of the
10 changes in the instantaneous energy as perceived by the human ear.

Further background can be found in the documents
US 5 884 260, WO 97/09712, WO 99/48085 and also in [1]
15 and [3], which are all incorporated herein by reference.

Summary of the invention

In accordance with the invention an excitation signal is fed to the device under test. The excitation signal is
20 preferably a swept or a stepped sine wave signal. A response signal from the device under test is analysed for transients, which preferably involves band pass filtering in one or more distinct frequency bands, rectification of the band pass filtered signals and low
25 pass filtering of the rectified signals. The signals thus analysed for transients are differentiated. After differentiation the signals represent, in each frequency band, the slope or steepness of the response signal from the device under test, and are a good and reliable
30 quantitative measure of the presence of possible rub and buzz in the device under test.

In quality control of eg microphones and speaker transducers each of these steepness signals is compared to a predefined threshold value. Transducers with steepness values entirely below the threshold value or values will pass the quality control test, whereas transducers with steepness values exceeding the threshold value in one or more frequency bands, have failed in the quality control test. Devices that have failed in the test may then be discarded or possibly repaired.

10

Brief description of the drawings

Figure 1A shows the sound output from eg a loudspeaker excited by a sine wave sweep, where the loudspeaker suffers from rub and buzz,

15

Figure 1B shows the signal in Figure 1A after band pass filtering,

Figure 1C shows the instantaneous energy pulses caused by rub and buzz,

20

Figure 2A shows schematically a set-up for transient analysis,

Figure 2B shows a schematic block diagram for energy detection by means of envelope detection,

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Figure 3A shows a series of measurements of a good transducer without rub and buzz,

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Figure 3B shows a series of measurements of a transducer suffering from rub and buzz,

Figure 4A shows a series of measurements of a good loudspeaker without rub and buzz,

- 5 Figure 4B shows a series of measurements of a loudspeaker with dragging coil,

Figure 4C shows a series of measurements of a loudspeaker with litz wire defect,

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Figure 5A shows a series of measurements of a good tweeter without rub and buzz,

- 15 Figure 5B shows a series of measurements of a tweeter with dragging coil,

Figure 5C shows a series of measurements of a tweeter with air leak,

- 20 Figure 6 shows a block diagram of a transient analyser used in the invention,

Figure 7 illustrates the principle of edge detection, and

- 25 Figure 8 illustrates the principle of masking edge detection.

Detailed description of the invention

- 30 The method by which the rub and buzz is detected according to the invention is based on detection of changes in the instantaneous energy by means of transient analysis. Theoretically, acoustic energy in a sound signal consists of kinetic energy and potential energy, and the total energy $E(t)$ is the sum of the kinetic energy and the potential energy, which can be expressed by the following formula:

$$E(t) = f^2(t) + \hat{f}^2(t) \quad (1)$$

where $\hat{f}(t)$ is the Hilbert transform of $f(t)$, and $f^2(t)$ and $\hat{f}^2(t)$ can be interpreted as the kinetic and potential energy, respectively. For a pure sinusoidal sound signal the total energy is constant. If $f(t) = \sin(\omega t)$, then $\hat{f}(t) = -\cos(\omega t)$, and consequently, $E(t) = \sin^2(\omega t) + \cos^2(\omega t) = 1$, ie a constant.

10 Ideally, when applying a sinusoidal signal to a loudspeaker the total energy measured acoustically, ie sound energy, should be constant, and therefore no changes in the instantaneous energy would be detected. However, if the loudspeaker suffers from rub and buzz, 15 the instantaneous energy will no longer be constant, and the rub and buzz can then be detected by detecting the relatively abrupt changes in the energy. Figures 1A-C show the result from an analysis of a loudspeaker suffering from rub and buzz when a swept sine is applied.

20

Figures 1A-C show both the time signal and the total instantaneous energy. In Figure 1A it can be seen that the amplitude of the sine wave signal is varying, which means that the energy is not constant. The abrupt changes 25 reveal the rub and buzz. In figure 1A the signal is a fraction of a sine sweep from a loudspeaker that suffers from rub and buzz. In Figure 1B the signal in Figure 1A is band-pass filtered, and in Figure 1C the signal is the envelope of the band-pass filtered signal.

30

Measurement set-up

Figure 2A shows a typical measurement set-up. The test object is a loudspeaker, but the invention is useful also to other audio devices such as amplifiers or other
5 equipment in an audio chain. A signal generator is used to supply the loudspeaker with an excitation signal, e.g. a sinusoidal signal. Preferably, a swept sine wave signal is used as excitation signal, where the frequency of the sine wave signal is varied eg linearly or logarithmically
10 between a lower limit and an upper limit. Alternatively, the frequency can be stepped through the frequency range of interest with the frequency being kept substantially constant for a predetermined period of time, which can vary with the frequency.

15

The sound output from the loudspeaker is picked up by a microphone and fed to a transient analyser implemented in a properly programmed computer, eg by means of the HARMONITM software from the applicant. With proper signal
20 conditioning the received signal is passed on to the sound card in the PC. Such a system is shown schematically in Figure 6.

Measurement and calculations

25 Pulses with short rise time or fall time, eg pulses termed as rub and buzz, will contain a broad spectrum of frequencies. Therefore it is possible to detect the instantaneous energy by detecting the energy in frequency bands in an interval in the transient or pulse oriented
30 range of the ear. According to the invention a method for doing this is to use a filter bank containing a group of band-pass filters covering the frequency interval of interest, and rectify and low-pass filter the outputs

from the filter bank. The output from the low-pass filters is an expression for the square root of the energy. To be able to measure and detect the dynamic instantaneous energy of a signal, it is crucial that the duration impulse response of the filters are sufficient shorter than the energy pulses signal.

Fig. 7 shows the principle of the edge or slope detection. The envelope signal is differentiated, and if the differentiated signal numerically exceeds a trigger level, which level can be adjusted by the user, a leading edge or a trailing edge is detected. Numerically the maximum slope of the leading or trailing edge is detected by finding the numerically local maximum of the differentiated envelope signal. Two thresholds define the beginning and ending of an edge. The edge begins where the differentiated envelope signal is equal to the threshold for the beginning of the edge before the local maximum, and it ends where the signal is equal to the threshold for the ending of the edge after the local maximum. The thresholds are expressed as a percentage of the maximum slope.

Figure 2 shows a practical set-up for measuring the energy as expressed in eq. (1). The set-up in Figure 2 comprises a band pass filter followed by a rectification followed by a low pass filter. This method can be characterised as transient analysis as energy detection by means of envelope detection. The rub and buzz shown in Figure 1 is found by this method.

The band pass filters are selected in accordance with the critical bands described by amongst others E. Zwicker [2]. Each band pass filter thus covers substantially one critical band. The purpose of the band pass filters is that the energy is found in frequency bands. The benefit of finding the energy in this way is that the changes in the instantaneous energy are detected and measured substantially as it is perceived by the human ear.

10 The low pass filters are preferably chosen in a way that ensures that no or only an insignificant overlap exists between the band pass filter and the low pass filter. In order for the method to detect rapid changes it is desirable that the low pass filter has a cut off
15 frequency as high as possible. The low pass filter is therefore chosen as a compromise between these 2 constraints. It is believed that this compromise also exists in the human ear.

20 In [1] a realisation of the transient analyser with 6 frequency bands each having a band pass filter, a rectifier and a low pass filter is described.

In order to get an interpretable result it is necessary
25 to find a way to express the changes in the instantaneous energy. The changes in the energy can be conceived as pulses. The pulses can be characterised by their magnitude, steepness and/or rise and fall time. By using one or more of these metrics it is possible to set up
30 appropriate limits in a QC system with reference to a pass/fail procedure.

Practical implementation and measurement

The measurement method is preferably implemented in software such as HARMONITM from the applicant, which software is described in the product specification sheet
5 "Transient Analyser - HARMONITMLab" [3]. The software has 6 channels or bands each having a band pass filter, a rectifier and a low pass filter as in Figure 2 and described above. The filters and also the number of bands can be changed by the user.

10

Figure 6 shows an equipment for a practical measurement could consist of a microphone with proper signal conditioning, a computer with a sound card, and an amplifier.

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The signal that is applied to the terminals of the loudspeaker is a swept sine as this has proven to be effective to find rub and buzz. Other types of signal like white or pink noise, MLS (Maximum Length Sequence)
20 may prove to be useful but this has not been examined. Using a sweep has the advantage that it is possible to track at which frequencies the rub and buzz is excited.

Filter Bank - Low and Band-pass filters

25 The background for using band-pass filters is based on the assumption that the ear can be divided into several filters as reported by amongst other E. Zwicker.

The purpose of the band pass filters is to detect the
30 pulse in the frequency band where the pulse has most energy as perceived by the human ear. It will be the filter where the shape of the impulse response best matches the shape of the pulse. The theoretical optimal

match is an impulse response with a shape equal the pulse but reverse in time. In many cases the pulses will decline exponentially and it would not be possible to have a stable causal filter with an impulse response that
 5 is exponentially increasing without being unstable.

A reasonable choice of filters that matches the filters in the cochlea is band-pass filters with the same value for Q equal to about 2.8.

10

	Band #	Frequency limits (-3 dB) in Hz
	1	1400 - 2000
	2	2000 - 2860
	3	2800 - 4000
15	4	4000 - 5720
	5	5700 - 8150
	6	8100 - 11580

The transient analyser preferably allows the user to
 20 define his own filters. Two types of Band-pass filters are preferred: the Butterworth and the RealPole type (see below). The RealPole type is chosen as default. The Butterworth filters are 6th order band pass filter with a maximally flat stop and pass. The RealPole filters are
 25 14th order band pass filters, with the same bandwidth as the Butterworth type.

To detect the energy in the bands the output signal from the band-pass filters has to be rectified and low-pass filtered. The spectrum of band-pass filters and the low-pass
 30 filters should not overlap each other. The filters are therefore chosen to have a cut-off frequency half the bandwidth of the band-pass filters for the Butterworth types of filters and a third of the bandwidth for the RealPole types.

	Band #	Low Pass (- 3 dB) Band in Hz for the Butterworth type
	1	300
	2	430
5	3	600
	4	860
	5	1225
	6	1740
10	Band #	Low Pass (- 3 dB) Band in Hz for RealPole type
	1	200
	2	287
	3	400
15	4	574
	5	817
	6	1160

The Butterworth filters' impulse responses have a long
 20 ringing tail. This ringing causes unwanted small
 transients to be detected, which do not correspond to
 actual conditions in the device under test. The RealPole
 filter type is based on a low pass filter with roots only
 on the negative real axis in the analogue S-domain. These
 25 filters are transformed to Band Pass filters, before the
 finally transformation to the digital domain. In theory
 the impulse response of the filters is infinite but in
 practice it has finite duration. The shorter the duration
 is for the impulse response the better is the time
 30 resolution, but the shorter the impulse response is, the
 less the frequency selection is. Therefore there is a
 limit on how short the impulse response can be, because

the spectrum of the band pass filter and low pass filter must not overlap each other. If they do the envelope detection will be mixed with frequencies.

5 **Pulse detection**

Figures 1A-C show an example of pulses detected in one of the bands. In figure 1A the signal is the output from a loudspeaker that suffers from rub and buzz, in response to a short sine sweep. In Figure 1B the signal is band-pass filtered, and in Figure 1C the signal is the
10 envelope of the band-pass filtered signal.

Figure 7 shows the principle of the edge detection. The envelope signal is differentiated, and if the
15 differentiated signal numerically exceeds a predefined trigger level, which level can be adjusted by the user, a leading edge or a trailing edge is detected. Numerically the maximum slope of the leading edge or trailing edge is detected by finding the numerically local maximum of the
20 differentiated envelope signal. Two thresholds define the beginning and ending of an edge. The edge begins where the differentiated envelope signal is equal to the threshold for the beginning of the edge before the local maximum, and it ends where the signal is equal to the
25 threshold for the ending of the edge after the local maximum. The thresholds are expressed as a percentage of the maximum slope.

Masking trigger level with exponential damping

30 It might be convenient to reduce the amount of edges. If a pulse with less maximum instantaneous energy or longer rise/fall time follows a pulse it might not be detected by the ear. Therefore it is possible to choose a special

trigger mode called "Masking Trigger". The principle is shown on fig. 13. Fig. 13 shows two pulses with different steepness for the leading and trailing edges. When the first leading is detected the trigger level is increased to the maximum level of the differentiate pulse, and decreased exponentially by the trigger time constant. The trailing edge is less steep than the leading edge and the trigger time constant is too great, and the trailing edge is not detected. The leading edge of the next pulse is detected because the trigger level is decreased to a level less than maximum of the differentiated pulse.

A reasonable choice for the trigger time constant is in the interval 1 - 3 ms..

Examples

Below, three examples are given for which rub and buzz tests have been carried out. The tests have been carried out on 3 types of transducers. The measurement setup and software were as described above.

In Figures 3A-B, 4A-C and 5A-C the abscissa is a time scale from 0 to 2 s. With a swept frequency excitation signal each point on the abscissa time scale also represents a distinct frequency depending on the chosen frequency limits and sweep characteristics. The ordinate represents the steepness of pulses in the sound output signal of the transducer under test as measured above.

Figures 3A-B show screen dumps from HARMONITM transient analyser software with the result of a transient analysis for a good 15 mm transducer and a bad one suffering from

rub and buzz, respectively, both intended for use in mobile phones. The applied signal was a linearly swept sine from 300 Hz to 1 kHz.

- 5 In Figures 3A-B the dots show the detected pulses derived from measurement of the instantaneous energy. Each curve represents one of the 6 bands. The steepness is plotted against time, and the x-axis therefore represents a linear frequency scale from 20 Hz to 100 Hz.

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- From Figure 3B it can be seen that the bad transducer, which suffers from rub and buzz, has a very easily detected rub and buzz in a limited frequency range corresponding to the time when the sweep is passing about 550 Hz. The difference between the good and the bad transducer suggest that a pass/fail limit of about 5-6
15 $d\Delta\text{Pascal/s}$ [re 1 Pa/s] would be appropriate to catch the transducers with defects.

- Figures 4A-C shows the result of an analysis of a good and 2 defect 10 cm midrange speaker. The test signal was a swept sine from 20 Hz to 100 Hz. The steepness is
20 plotted against the time and the x-axis may therefore be conceived as a linear frequency scale from 20 Hz to 100 Hz. Figure 4 indicates that a pass/fail limit of about 0.5 $d\Delta\text{Pascal/s}$ [re 1 Pa/s] would be appropriate.

- 25 Figure 5 shows the result of a transient analysis on three 25 mm tweeters. One tweeter is without rub and buzz, one has a dragging coil defect and one has an air leak. The test signal was a swept sine from 20 Hz to 500 Hz. The steepness is plotted against the time and the x-
30 axis may therefore be conceived as a linear frequency scale from 20 Hz to 100 Hz. A pass/fail limit of about 0.5 $\Delta\text{Pascal/s}$ [re 1 Pa/s] would be appropriate.

In general the pass/fail limit can be set as a fixed value for all bands or a value can be set for each band. Further when a sweep is used as excitation signal it is also possible to set a limit as a function of the
5 excitation frequency. The limit(s) should reflect the level of acceptance.

An AGC (automatic gain control) amplifier is an option to simulate the masking effect in frequency. When the energy
10 i.e. loudness increases to a large value in one of the frequency bands, the AGC connected to the band will decrease the signal, stopping the edge detection. The AGC amplifier can be expressed with the equation:

$$15 \quad \frac{1}{1 + K_{AGC} \langle x(t) \rangle},$$

where $x(t)$ is the input signal (from the low pass filters) and K_{AGC} is a constant.

$\langle x(t) \rangle$ is the average (DC) at time t . In HARMONI Lab it is
20 an exponential average estimate, where the past values is weighted after an exponential window. With the time constant τ , the averaging speed is set. Generally applies that larger τ values gives a better average estimate, but a worse time resolution.

25

Literature

[1] Application note, "Measuring the instantaneous energy in signals", Leonhard Research A/S.

30

- [2] E. Zwicker, H. Fastl: "Psychoacoustics - Facts and Models".
Springer Series in Information Sciences.
- [3] Product specification sheet "Transient Analyser
5 - HARMONITMLab", Leonhard Research A/S.
- [4] A. B. Carlson: "Communication Systems: An
Introduction to Signals and Noise in Electrical
Communication". McGraw-Hill Electrical and Electronic
10 Engineering Series.
- [5] S. Seneff: "A joint synchrony/mean-rate model of
auditory speech processing". Journal of Phonetics
(1988) 16. 55-76.
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Claims

1. A method of testing an electro-acoustic device, the method comprising

5

- supplying a test signal to the device causing the device to respond with a response signal,

- capturing the response signal,

10

- analysing the captured response signal for transients, and

- deriving, from the transients, information indicative of the transients.

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2. A method according to claim 1, characterized in that the derived information indicative of the transients is chosen from the group consisting of steepness, rise time and magnitude.

20

3. A method according to claim 1, characterized in that the step of analysing the captured response signal for transients comprises

25

- band pass filtering the captured response signal to obtain a band pass filtered signal,

- determining an envelope of the band pass filtered signal.

30

4. A method according to claim 3, c h a r a c t e r -
i z e d in that the step of determining an envelope of
the band pass filtered signal comprises
- 5 - rectification of the band pass filtered signal to
obtain a rectified signal, and
- low pass filtering the rectified signal.
- 10 5. A method according to claim 3, c h a r a c t e r -
i z e d in that
- the captured response signal is band pass filtered in a
plurality of band pass filters to obtain a plurality of
15 band pass filtered signals, that
- each band pass filtered signal is rectified to obtain
respective rectified signals, and that
- 20 - each rectified signal is low pass filtered.
6. A method according to claim 1, c h a r a c t e r -
i z e d in that the step of deriving information
indicative of steepness of the transients comprises
25 differentiation of the transients.
7. A method according to claim 1, c h a r a c t e r -
i z e d in that the information indicative of steepness
of the transients is compared to a predefined threshold
30 value.

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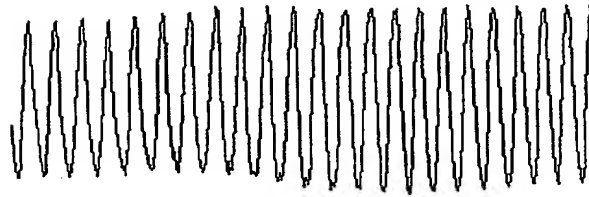


Fig.1A Sine wave sweep with Rub and Buzz



Fig. 1B Band-pass filtered signal

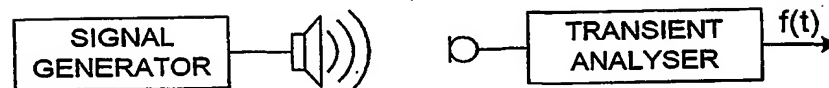
Fig 1C Instantaneous energy pulses
caused by Rub and Buzz

Fig. 2A Transient analysis setup



Fig. 2B Energy detection by means of envelope detection

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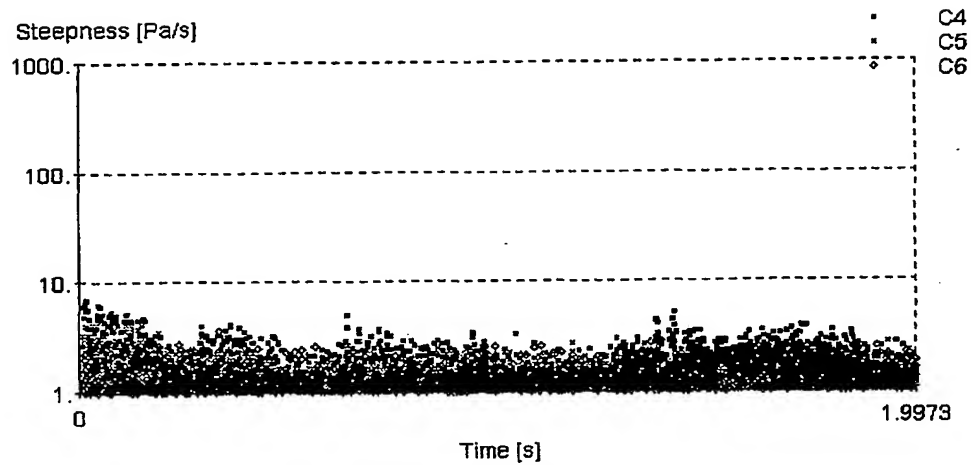


Fig. 3A Transducer without Rub and Buzz

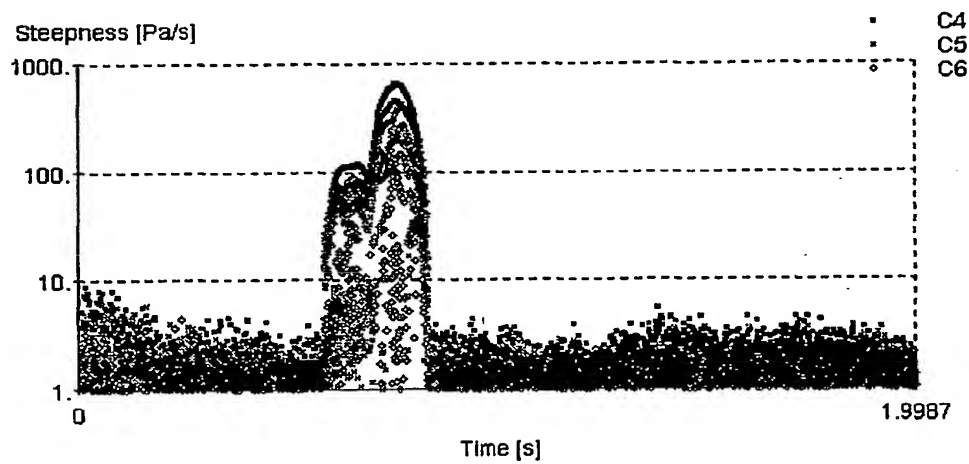


Fig. 3B Transducer with Rub and Buzz

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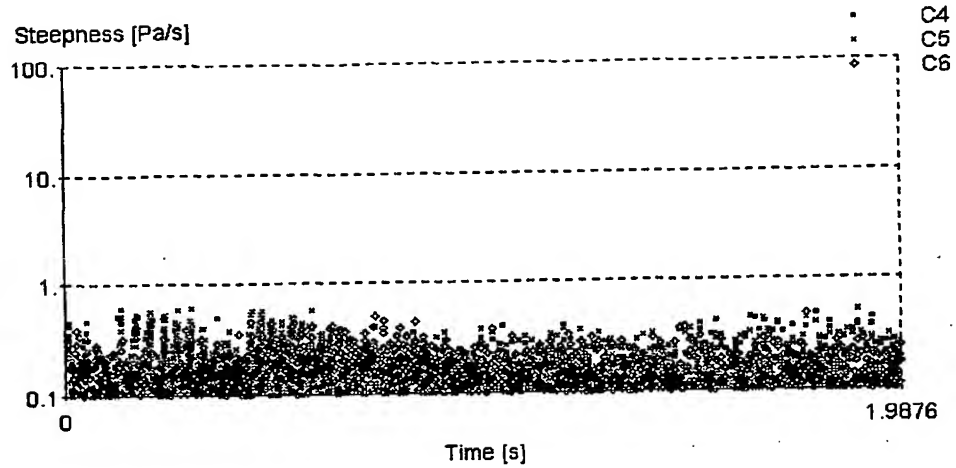


Fig. 4A Loudspeaker without Rub and Buzz

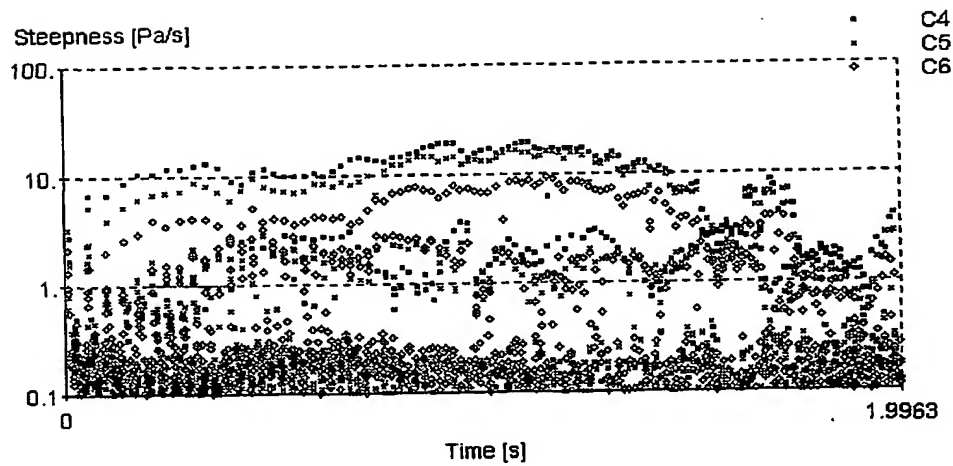


Fig. 4B Loudspeaker with dragging coil

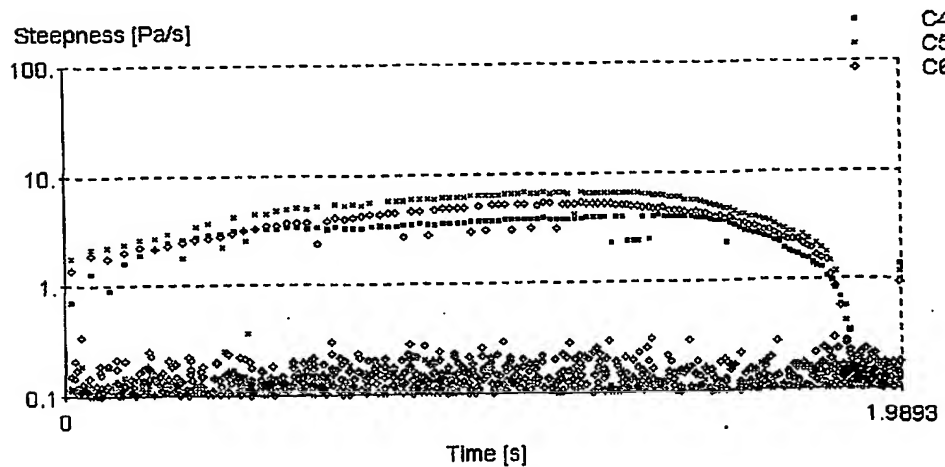


Fig. 4C Loudspeaker with litz wire defect

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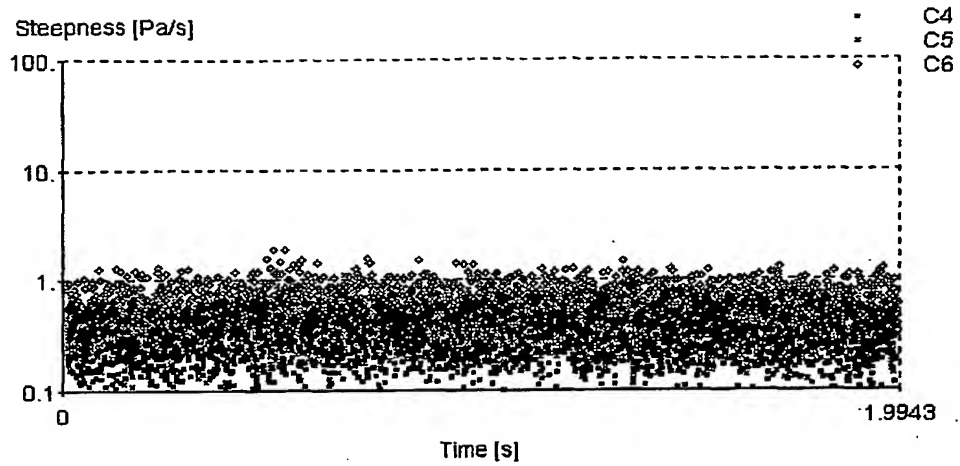


Fig. 5A Tweeter without Rub and Buzz

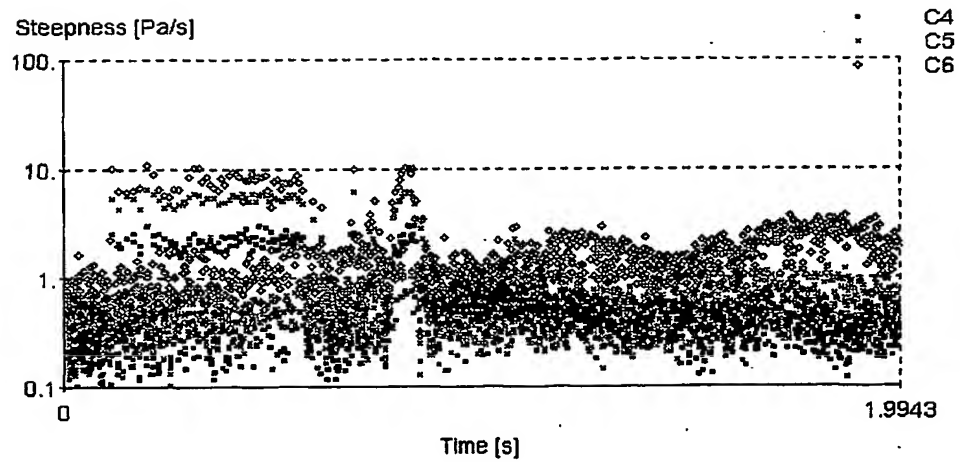


Fig. 5B Tweeter with dragging coil

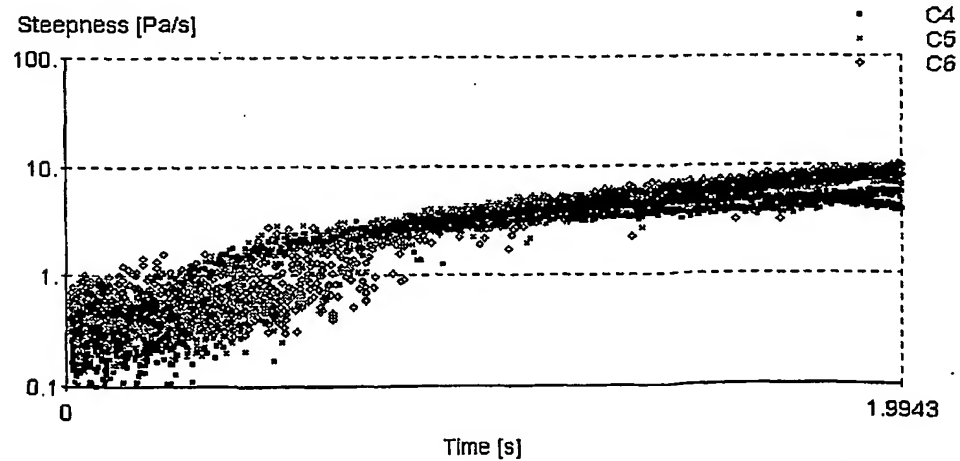


Fig. 5C Tweeter with air leak

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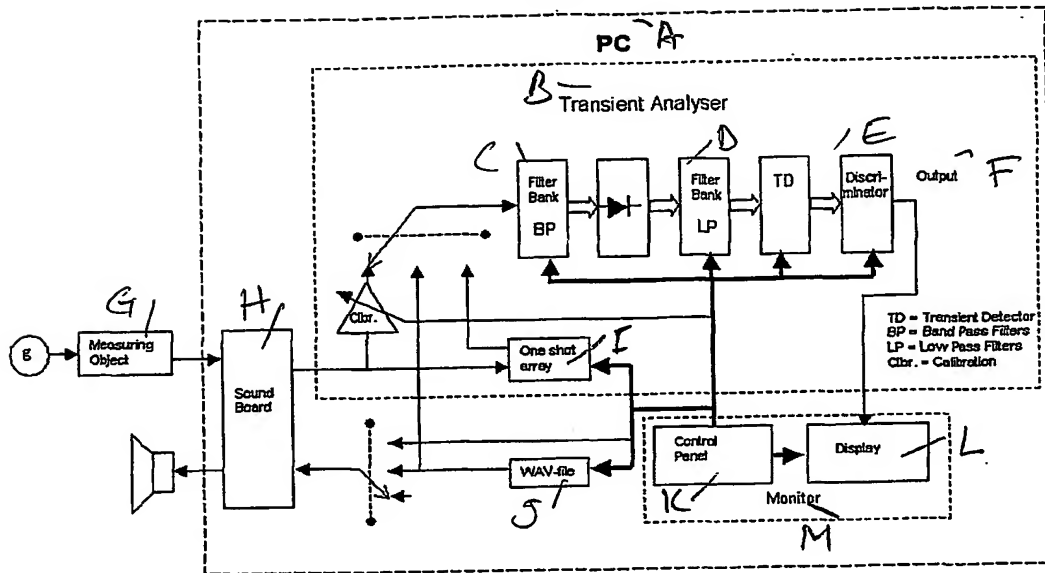


Fig. 6 Block diagram of transient analyser

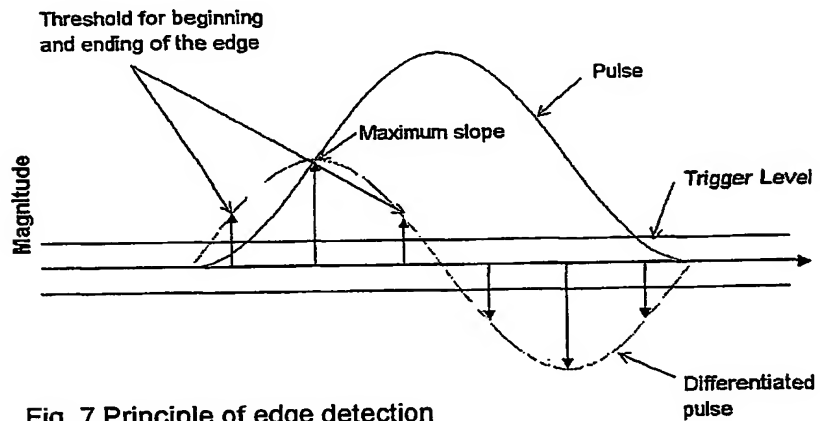


Fig. 7 Principle of edge detection

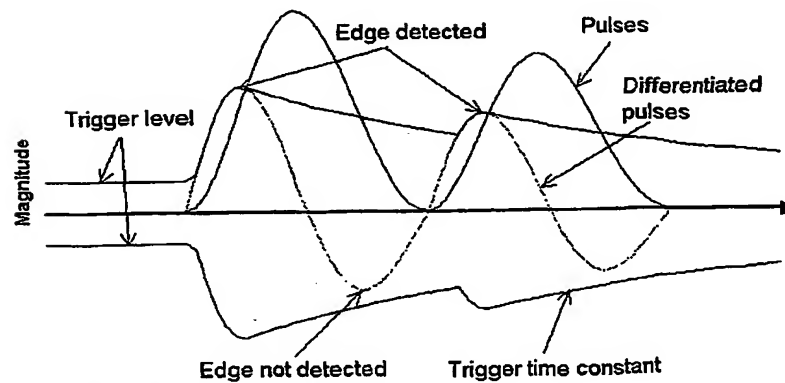


Fig. 8 Masking edge detection

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 01/00605

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04R 29/00 // G10L 17/00, G10L21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04R, G10L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 9425958 A2 (LEONARD, F.U.), 10 November 1994 (10.11.94), the whole document --	1-7
X	WO 9709712 A2 (LEONARD, F.U.), 13 March 1997 (13.03.97), the whole document --	1-7
A	WO 9948085 A1 (LEONARD, F.U.), 23 Sept 1999 (23.09.99) --	1-7
P,A	WO 0131632 A1 (THE UNIVERSITY OF MELBOURNE), 3 May 2001 (03.05.01) -- -----	1-7

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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Information on patent family members

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Patent document cited in search report			Publication date	Patent family member(s)		Publication date
WO	9425958	A2	10/11/94	AT	178155 T	15/04/99
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				EP	0737351 A,B	16/10/96
				FI	955025 A	15/12/95
				JP	8509556 T	08/10/96
				US	5884260 A	16/03/99
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